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Differential-frequency Doppler weather radar: Theory and experiment

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[1] To move toward spaceborne weather radars that can be deployed routinely as part of an instrument set consisting of passive and active sensors requires the development of smaller, lighter-weight radars. At the same time, the addition of a second frequency and an upgrade to Doppler capability are essential to retrieve information on the drop size distribution (DSD), vertical air motion, and storm dynamics. One approach to the problem is to use a single broadband transmitter-receiver and antenna where two narrowband frequencies are spaced apart by 7–10%. Use of Ka-band frequencies (26.5–40 GHz) provides adequate spatial resolution with a relatively small antenna. Moreover, the differential reflectivity and mean Doppler signals in this band are directly related to the median mass diameter of the snow and raindrop size distributions. We present in the paper theoretical calculations of the differential reflectivity and Doppler for several frequency pairs including those proposed for the Global Precipitation Mission (GPM) at 13.6 and 35 GHz. Measurements from a zenith-directed radar operated at 9.1 and 10 GHz are used to investigate the qualitative characteristics of the differential signals. Disdrometer data taken at the surface, just below the radar, show that the differential signals are related to characteristics of the raindrop size distribution. The stability of the DSD estimation procedure is tested using a simulation. The results indicate that reasonably stable estimates of the particle size distribution are feasible with a [31.5 GHz, 35 GHz] combination as long as a large number of independent samples are obtained. *INDEX TERMS:* 0360 Atmospheric Composition and Structure: Transmission and scattering of radiation; 0629 Electromagnetics: Inverse scattering; 0694 Electromagnetics: Instrumentation and techniques; 1854 Hydrology: Precipitation (3354); 3360 Meteorology and Atmospheric Dynamics: Remote sensing; *KEYWORDS:* Doppler, radar, differential-frequency, rain, spaceborne radar, drop size distribution

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1. Introduction and Background

[2] The Precipitation Radar (PR) aboard the Tropical Rain Measuring Mission (TRMM) satellite has performed nearly flawlessly since its launch in December 1997 [*Kozu et al.*, 2001]. The PR is the first weather radar to be flown in space and the question arises as to the design of the next-generation weather radar. This question has been answered, in part, by the proposed radar for the successor to TRMM, the Global Precipitation Mission (GPM). The tentative plan for the GPM radar is to employ dual-frequencies at 13.6 GHz and 35 GHz, with phased-array antennas that scan cross-track with beam widths matched at the two frequencies. This dual-frequency precipitation radar, DPR, should provide more detailed information on the drop size distribution and phase state of the hydrometeors (liquid, frozen, and mixed-phase) than does the present single-frequency 13.8 GHz PR. The DPR should also provide an increase in the dynamic range of observable rain rates and better accuracy in the estimates of rain rate and liquid and ice water contents. In this paper we focus on an alternative design strategy that makes use of the differential-frequency concept. The

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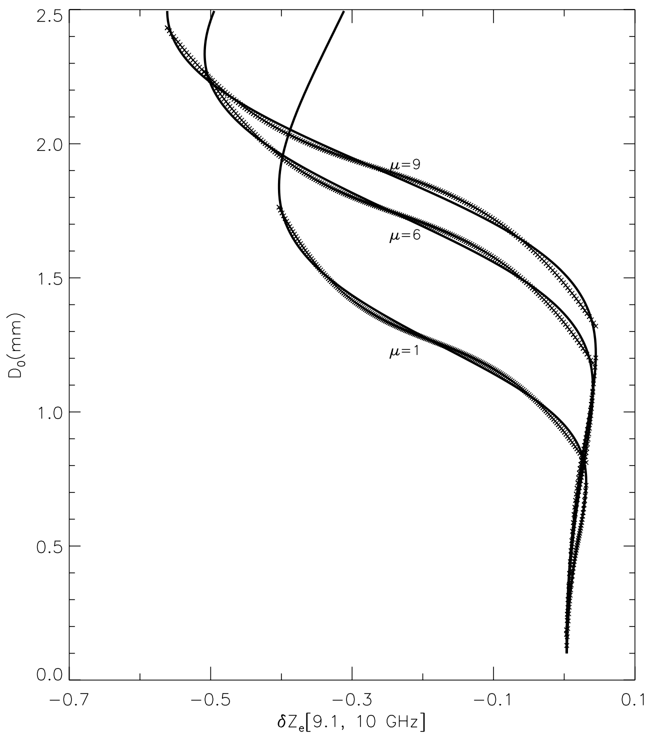

Figure 1. D_0 versus δZ_e[9.1, 10 GHz] for 3 values of μ along with cubic fits to the lower and upper branches (X).

essence of the idea is to reduce the spacing between the two frequencies so that a single antenna and the same radio-frequency subsystem can be used for both frequencies. The resulting reduction in size and mass suggests the possibility of weather radars aboard smaller satellites or as an add-on instrument to weather-related satellites that are presently equipped with only passive radiometers.

5. Summary and Conclusions

[19] By the use of a broadband antenna and power amplifier, it is possible to measure differential-frequency data using a radar that is not much larger or more complex than its single-frequency counterpart. Theoretical calculations indicate that differential Doppler and differential reflectivity data can be measured if a sufficient number of independent samples can be collected. Frequencies at Ka-band with a separation on the order of 7% to 10% are attractive in that a modest antenna size (less than 1 m diameter) from low-Earth orbit can achieve a TRMM-type resolution of 4 km at the surface. Moreover, at these frequencies, the differential signals are relatively strong and closely related to the median mass diameter of the particle size distributions. Data measured at 9.1 GHz and 10 GHz by the EDOP radar in a zenith-viewing mode suggest that the differential velocity and reflectivity signals can be measured even at X-band frequencies and that the δZ_e (and to a lesser extent the δv) signature is closely related to characteristics of the drop size distribution. While this is encouraging, it remains to be shown that the differential-frequency approach can estimate accurately the drop size distribution. To investigate this question, integral equations for the solution of the DSD parameters were presented in initial- and final-value forms. Simulated radar data from the [13.6, 35 GHz] and [31.5, 35 GHz] frequency pairs lead to reasonably good retrievals of D_0 if the final-value forms of the equations are used. A partial resolution of the ambiguities in μ and in the retrieval of D_0 from δZ_e appears possible with some refinements in the algorithm. The greatest drawback of the differential reflectivity approach is the need for large numbers of independent samples: simulations indicate unacceptably high errors in the estimates when this number falls below about 1000. Pulse compression, frequency agility and "whitening" [*Koivunen and Kostinski*, 1999] methods can be used to increase the number of independent samples. Nevertheless, the differential-frequency mode for airborne or spaceborne weather radar is best suited to nonscanning applications where there is usually sufficient time to acquire large numbers of samples.